

Quid refert igitur, quantis jumenta fatiget
Porticibus —————

And both together, the use and destination of the building, which is the subject of our Inscription, BASILICA (*i. e.* porticus) EQVESTRIS EXERCITATORIA.

As the Roman affairs in Britain are little known under this emperor; one only Inscription besides, as I observed, either bearing his name, or referring to his age, these notices may possibly be more welcome. And what makes the first Inscription more so, is the mention of a new Legate, or lieutenant and pro-prætor, Valerianus, in this province, never taken notice of before. A copper Inscription lately discovered in the estate of the D. of Norfolk in Yorkshire, and now in his Grace's possession, affords us another, and that a very remarkable personage, under the emperor Hadrian, and one much known in the Roman history.

What was the prænomen of this Legate, l. 9. is a matter of farther enquiry.

XXIX. *A Method of lessening the Quantity of Friction in Engines*, by Keane Fitzgerald, Esq; F. R. S.

Read May 12,
1763.

M ECHANICS, or that branch of mathematics which considers motions and moving powers, their nature and laws, is properly distinguished into rational, and practical.

A knowledge in rational mechanics, which comprehends the whole theory of motion, upon which natural philosophy so greatly depends, is chiefly confined to the learned; and the proper construction of engines and machines, which is the principal object of practical mechanics, altho' so very necessary to carry on the several branches of husbandry, manufacture, and commerce, upon which, the riches and power of a nation depend in a great measure, is seldom attended to, but by the meer handicraftsman; who is little acquainted with the principles he works on, and from whom no great improvements can well be expected; yet it has happened sometimes, that excellent contrivances have been invented, for raising heavy weights and overcoming their resistances, by persons who never took the trouble of examining into the cause of gravity.

As this branch is certainly most useful to mankind, and a knowledge in it, generally deemed one of the marks by which a civilized nation is distinguished from barbarians, one would imagine, it should have induced a greater attention to improvements in it, than has been generally found: But it often happens that mechanical powers, seemingly demonstrable in theory, are found very deficient in operation, from unexpected obstructions; which, with the expence and trouble that generally attend the reducing speculations of this nature into practice, have probably been the greatest obstacles to improvements in it.

One of the greatest obstructions to the mechanical powers of engines proceeds from the friction, or resistance of the parts rubbing on each other; which in general, is greater, or less, as the rubbing
parts

parts bear the greater, or less pressure; and yet this obstruction is but little attended to. The theorist makes no allowance on account of friction; and the practical mechanic, who feels the effects, yet, as if unavoidable, seldom takes the trouble of searching for a remedy.

Amongst the few who have endeavoured to ascertain the quantity of friction proceeding from weight, some have deemed it equal to $\frac{1}{3}$, others to $\frac{1}{2}$, and others more, or less, according to their different methods, or accuracy in making experiments. Doctor Defaguillers gives an account of some experiments, which shew the quantity of friction in a cylinder, to be equal to $\frac{2}{3}$ of the power required to move it, when the surface of the cylinder moves as fast as the power.

In order to examine the quantities of friction proceeding from different weights, I had an exact balance made, which weighed 27 ounces; the pivots of the axis were $\frac{1}{2}$ inch diameter, and turned in brass sockets, fixed in a frame for the purpose.

Seven pound suspended on each arm, at 18 inches distance from the center, required $1\frac{1}{2}$ ounce, 2 penny weight, to be applied to either end, to overcome the resistance from friction in the slightest degree; and 3 ounces to carry it down 2 inches.

Fourteen pound, applied in the same manner, required $3\frac{1}{8}$ ounces to move the balance; and $6\frac{1}{4}$ ounces to sink either end 2 inches.

Twenty one pound required $4\frac{1}{4}$ ounces to give it the least motion, and $7\frac{3}{4}$ ounces to sink it about 2 inches.

Seven pound, suspended on each arm at 9 inches distance from the center, required 3 ounces and $\frac{1}{4}$ to move either end in the least degree.

Fourteen

Fourteen pound required $6\frac{3}{4}$ ounces ; and 21 pound required $9\frac{1}{4}$ ounces.

I placed another axis in the same ballance, the pevets of which were 1 inch diameter, and suspended 7 pound on each arm at 18 inches distance from the center, which required $3\frac{3}{4}$ ounces to be applied to either end, to overcome the resistance from friction ; and then that end sunk near 2 inches.

Fourteen pound, applied in the same manner, required $7\frac{1}{2}$ ounces, which carried that end down somewhat more than 2 inches.

Twenty one pound required $11\frac{3}{4}$ ounces, and sunk either end $2\frac{1}{2}$ inches.

Seven pound, suspended on each arm at nine inches distance from the center, required $7\frac{1}{2}$ ounces to move either end. — Fourteen pound required 14 ounces, and 21 pound required $20\frac{1}{2}$ ounces.

On repeating these experiments, there was little or no variation ; and altho the several powers, required to overcome the resistance from friction, do not correspond exactly in proportion to the several weights and distances ; yet it appears, that the least power required, was equal to $\frac{1}{4}$ the weight on the pevets ; and that it required a power nearly equal to the whole weight, to overcome the resistance from friction, with but a small degree of velocity. But it does not follow, that the extraordinary power, seemingly required to overcome the friction with this degree of velocity, is to be attributed entirely to that cause, as part of it is necessary to raise the opposite weight with the same degree of velocity, tho' some part of it certainly is. For when there is little or no obstruction from friction,
a power

a power of one ounce, more than what is just necessary to counterballance a weight of 7 pound, will raise it with as great a degree of velocity, as 2 ounces over and above what is just necessary to overcome the resistance from friction. So that it must require an additional power in proportion, to overcome the resistance from friction, with the same degree of velocity, that it may be necessary to raise the weight.

It is not imagined that these experiments should determine the exact quantity of friction proceeding generally from weight, or pressure; which probably can never be ascertained by any experiments, however accurate; for even in engines of equal dimensions, and loaded with equal weights, the quantities of friction may be very unequal, from circumstances differing, which are sometimes imperceptible; such as the firmness, elasticity, roundness and smoothness of the parts rubbing on each other; particularly the roundness, and smoothness of the gudgeons, or pevets, which, in large engines, are seldom turned true, or polished. But it appears from these experiments, that the quantity of friction in large engines may reasonably be estimated at $\frac{1}{2}$ the weight, or pressure, on the rubbing parts; although in such as are small, and finished with exactness, the quantity may probably be about $\frac{1}{3}$.

It is evident that the quantity of friction in any engine, is equal in its opposition to a certain portion of weight, or pressure on the parts rubbing on a dead surface. And, altho' gravity is an active principle always tending to a center, and friction, a kind of vis inertiae in opposition to motion, yet it may be considered mechanically as so much weight which requires a power to overcome its resistance, in
a ratio

a ratio of the velocity of the power, to the velocity of the part rubbing on a dead surface; as in the axis in peritrochio, TAB. XII. Fig. 1. If the wheel A be 20 feet diameter, the axis B 1 foot diameter, the pevets f of the axis B 4 inches diameter, and the weight C to be raised by the axis B, 12 tons or 24,000 pounds

The power D, in the wheel A, with respect to the weight C to be raised on the axis B, is required in a ratio of the semidiameter of the wheel A to the semidiameter of the axis B, which is $\frac{2}{1}$; therefore the power D = 1200 pound is sufficient to counterballance the weight C, and the least additional power would raise it, if there were noobstruction. But the quantity of friction in the pevets f , supposed equal to $\frac{1}{2}$ the weight or pressure on that part, requires an additional power in the wheel A to overcome its resistance, in a ratio of the semidiameter of the wheel A, to the semidiameter of the pevets f , or of the velocity of the power in the wheel A, to the velocity of the part rubbing on a dead surface in the pevets f , which are $\frac{6}{1}$. And as the weight of the wheel A, supposed 1500 pound, also the power D 1200 pound, required to counterballance the weight C 24,000 pound, in all 26,700 pound; center in the pevets f , the quantity of friction in the pevets f , being equal to $\frac{1}{2}$ the weight, or 13,350 pound hanging on them, will require a power in the wheel A somewhat more than $220 \frac{5}{6}$ pound to overcome its resistance. And as this additional power E $220 \frac{5}{6}$ pounds causes an additional friction = $110 \frac{5}{12}$ pounds, it also requires a further power K = $110 \frac{5}{6}$ pounds to overcome its resistance; but the quantity of friction proceeding from thence, need not be estimated in a calculation of this nature.

As

Fig. 3.

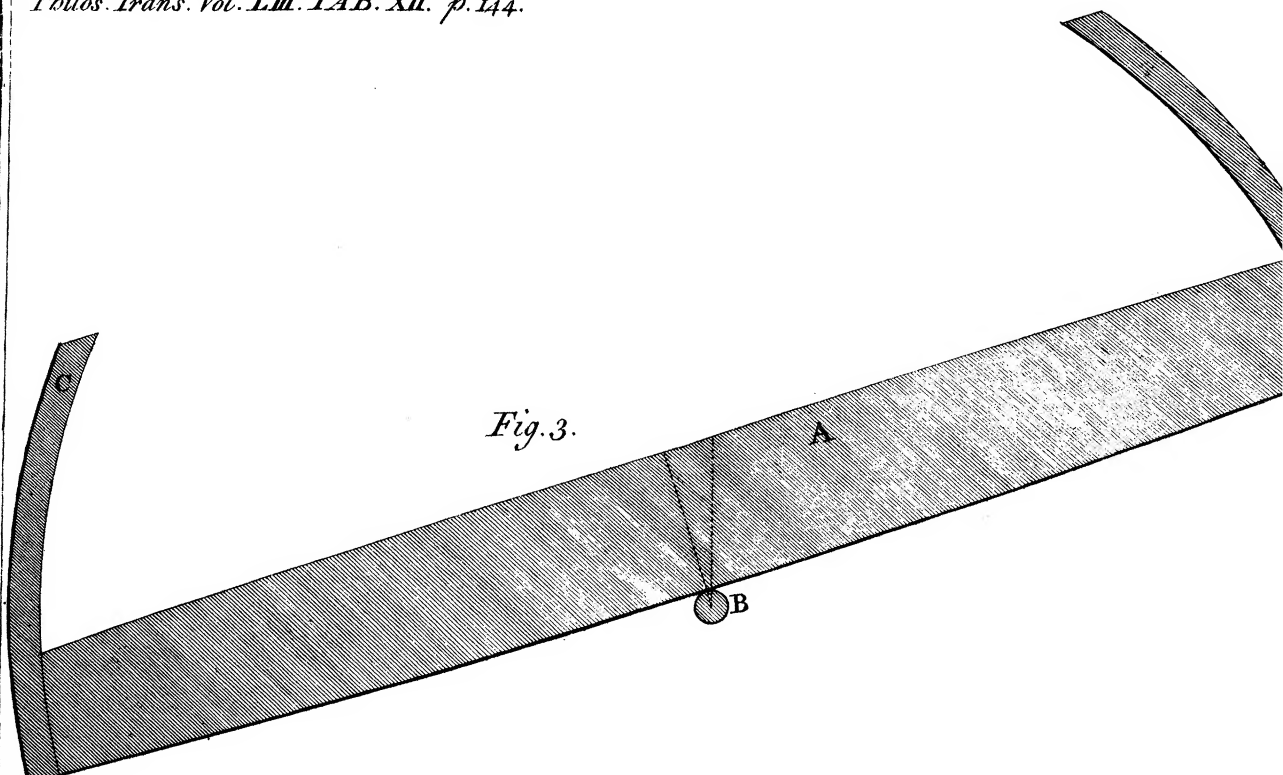


Fig. 4.

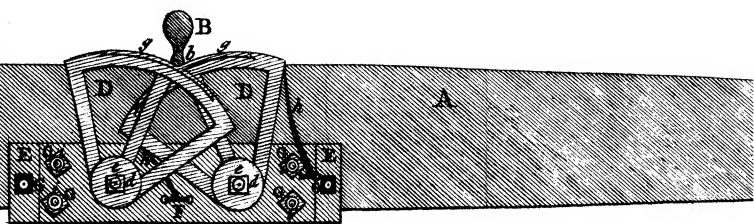


Fig. 1.

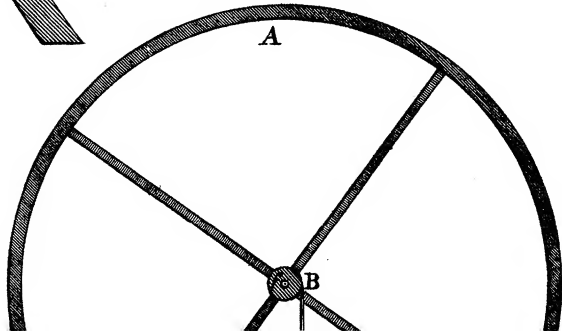
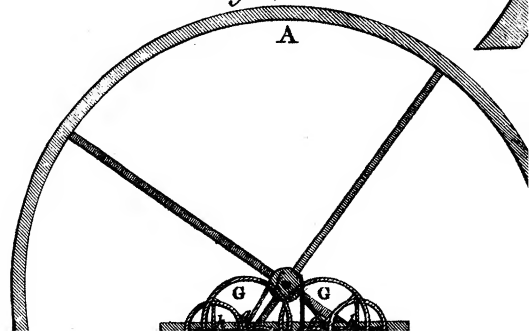
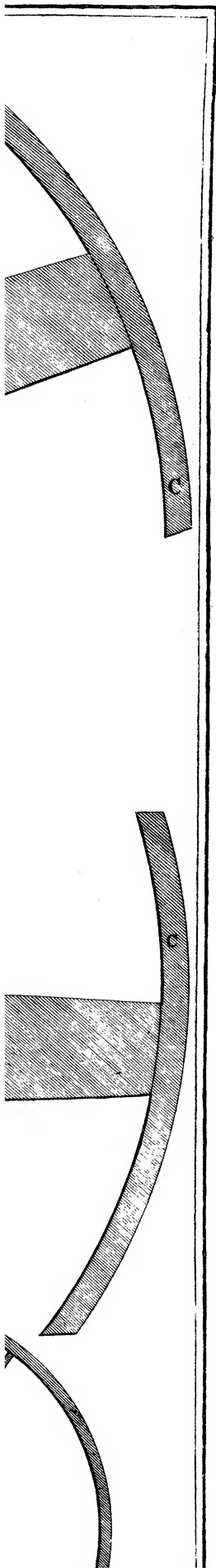
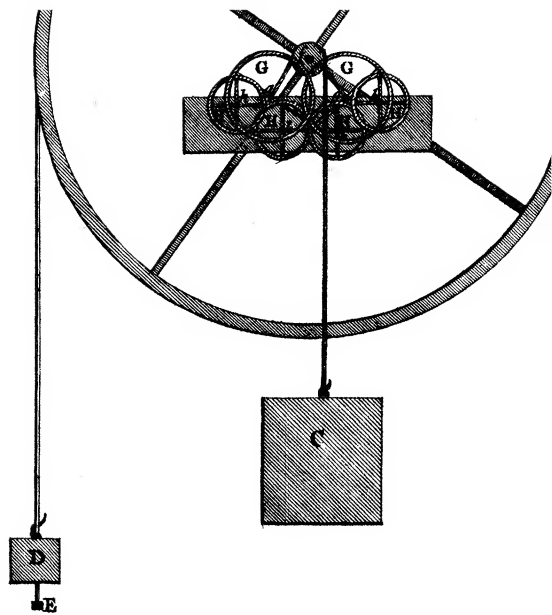
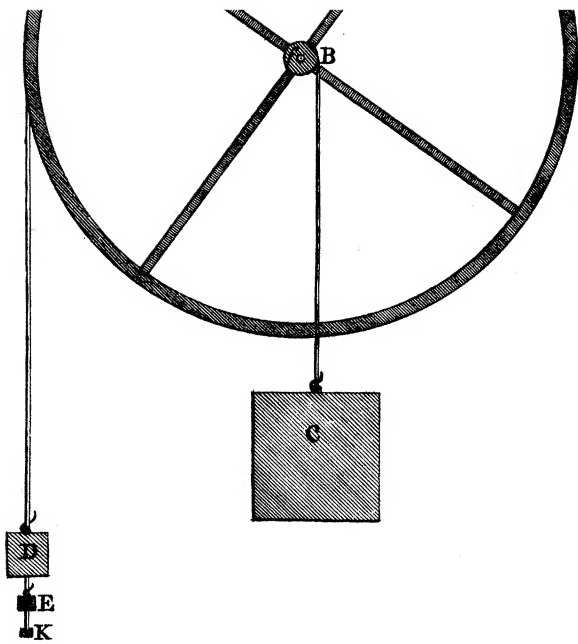
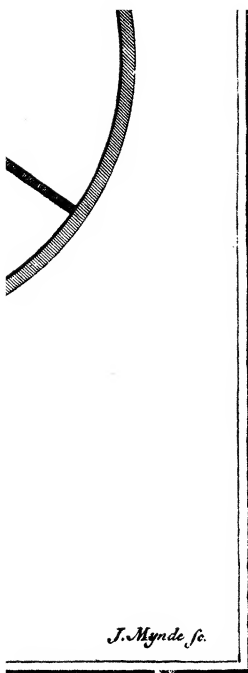


Fig. 2.









J. Mynde sc.

As the power E, in the wheel A, with respect to friction in the pevets f , is in a ratio of the semidiameter of the wheel A to the semidiameter of the pevet f , it is evident, that, by enlarging the diameter of the wheel A, or reducing the diameter of the pevets f , the power over friction will be increased in proportion; but whatever power is gained by enlarging the diameter of the wheel A, will be lost equally in time, or velocity, with respect to the weight C to be raised; and altho' there will be no loss in time, or velocity, by reducing the diameter of the pevets f ; yet this cannot be done beyond the proper degree of strength required to sustain the weight C &c.

As it also appears that the power E with respect to friction in the pevets f , is in a ratio of its velocity to the velocity of the pevet f rubbing on a dead surface, it follows, that if the velocity of the part rubbing on a dead surface can be decreased, whilst the velocity of the power D continues in the same ratio, with respect to the weight C to be raised on the axis B; the power E over friction, will be increased in proportion, without any loss in time or velocity, as to the weight C to be raised; which may be effected in the following manner, and the quantity of friction reduced to any degree that may be required.

Fig. 2. Let the pevets f of the wheel A, turn on the peripheries of the wheels G. G. 3 feet diameter, whose pevets g, g , are 1 inch diameter, and the whole friction will be transferred from the pevets f , to the pevets g , which will then be the only parts rubbing on a dead surface, by which means the velocity of the power in the wheel A, to the velocity of the pevets g , will be in a ratio of $2\frac{1}{4}^{\circ}$. For as the pevets f , 4

inches diameter, turn on the peripheries of the wheels G, 3 feet diameter, 9 revolutions of the pevet f , are equal to 1 revolution of the wheels G; and the circumference of the pevet f , being 4 times the circumference of the pevet g , the space the pevet f , would have rubbed on a dead surface in one revolution, is equal to the space the pevet g rub on a dead surface in 36 revolutions of the pevet f ; therefore the velocity of the pevet f , being $\frac{36}{1}$ to velocity of the pevet g , and the velocity of the power D in the wheel A being $\frac{60}{1}$ to the velocity of the pevet f , the velocity of the power D, to the velocity of the pevet g , is $\frac{60}{1} \times \frac{36}{1} = \frac{2160}{1}$. So that $\frac{1}{2160}$ of 13250 pound, which was the weight equal to the quantity of friction in the pevet f ; or a power somewhat more than 6 pound 2 ounces in the wheel A, will be sufficient to overcome the resistance from friction in the pevet g .

To reduce this quantity of friction to a less degree, let each of the pevet g , be placed on the peripheries of the wheels H, 2 feet diameter, whose pevet h are $\frac{1}{4}$ inch diameter; and the whole friction will then be transferred from the pevet g , to the pevet h ; by which the velocity of the power in the wheel A, to the velocity of the part rubbing on a dead surface, in the pevet f , will be in a ratio of $\frac{2160}{1}$. For the circumference of the pevet g , being $\frac{1}{24}$ of the circumference of the wheel H, on which it turns, makes 24 revolutions, for 1 of the pevet h . And the circumference of the pevet g , being 4 times the circumference of the pevet h , the space the pevet g would have rubbed on a dead surface in 1 revolution, is equal to the space the pevet h rubs in 96 revolutions; therefore

therefore the velocity of the pevet g , to the velocity of the pevet h , is $9^{\circ}6'$. And as it appears that the velocity of the power in the wheel A , is in a ratio of $2^{\circ}1^{\circ}6'$ to the velocity of the pevet g ; consequently its velocity to that of the pevet h , is $2^{\circ}1^{\circ}6' \times 9^{\circ}6' = 2^{\circ}7^{\circ}3^{\circ}6'$. So that $\frac{1}{207360}$ of 13,250 pound the quantity of weight deemed equal to the friction originally in the pevets f , or a power E somewhat more than 2 ounces, will be sufficient to overcome the friction in the pevets h .

Thus it is evident, that, by the application of additional wheels, or by enlarging the diameters of these, the resistance from friction may be reduced to less than the resistance of the medium the wheel passes through.

The whole weight which centers in the axis of the wheel A , being equally divided on the pevets f , and further subdivided on 32 pevets h , the weight on each of these pevets, being but $\frac{1}{48}$ of the weight on each of the pevets f , does not require more than $\frac{1}{48}$ of its strength. And as the quantity of friction in each of the pevets h is in proportion to the weight or pressure it bears, the sum of the several quantities of friction in the 32 pevets h , is equal to the quantity of friction that was originally in the 2 pevets f , in proportion to their velocities.

There is also some additional friction in the pevets h , on account of the weight of the wheels G and H ; but, with respect to the power in the wheel A , it is not of consequence to require a calculation.

There is no engine for raising heavy weights, that has less friction than the axis in peritrochio. If the same weight were to be raised by 2 wheels, one mul-

tipling the other ; the power in the first wheel, being in a ratio of $\frac{5}{1}$ to the weight to be raised, and $\frac{1.0}{1}$ to the friction in its pevets ; and the power of the second wheel in a ratio of $\frac{4}{1}$ to the weight, and $\frac{6}{1}$ to the friction in its pevets ; which powers are the same as in the wheel A, viz. $\frac{2.0}{1}$ with respect to the weight, and $\frac{6.0}{1}$ with respect to the friction ; although the powers required to counterballance the weight on the axis, are equal in each ; yet it would require a power above 733 pound to overcome the resistance from friction in this engine, which is nearly treble the power required to overcome the friction in the wheel A, on account of four pevets rubbing on a dead surface in one, and but two pevets in the other.

By reducing the friction in the pevets of this engine, in the same manner as in the pevets of the wheel A, the power 733 pound, which is required merely on account of friction, may be applied to raise an additional weight of 14,650 pound, without any diminution in point of time, or velocity, with respect to the weight to be raised ; which at first view may seem contrary to the general principle, that whatever power is gained mechanically over weight, is lost equally in point of time, and velocity ; and is so in reality, with respect to practical mechanism ; For the saving a power, otherwise, hitherto, found necessary to overcome the resistance from friction, and applying it to the useful purpose of raising a greater quantity of weight, in equal time, is, in effect, equal to an acquisition of so much power.

If these wheels are made with tolerable exactness, and placed, as in the drawing, on a line opposite to the point of pressure of the pevets they support, the
pressure

pressure will be equal on each wheel; and the greater the pressure, the more securely they are kept in their proper places. I have a double set of brass wheels, 8 inches diameter, with which I have made several experiments, and find the practice answer as near as possible to the theory. But as the expence of brass wheels, to large engines, would be very considerable, I had wheels made of wood, which I find to answer the purpose as well, if not better; as they are much lighter, and may be made strong enough to support a great weight, at a moderate expence.

The wooden wheels are fixed on an arbour, whose pevets have been turned true, and the edge of the wheel turned after it is fixed on the arbour. These wheels are placed in a wooden frame, with a small plate of brass fixed properly in the frame, for the pevets to turn in. They may be made with spokes, and fellies, capable of sustaining a considerable weight; and there is no danger of their wearing, as the pevet only rolls on the edge. I had wheels made of white deal, with several lamina glewed together, crossing each other in different directions of the grain of the wood, which hinders them from warping, or cracking; and which I found, upon trial, answered extremely well. By crossing the grain of the wood, the opposition to the pressure on the periphery is pretty equal in all parts; and the edge of the wheel, in a little time, becomes as smooth, and almost as hard as brass.

These wheels cannot be applied to wheel carriages, unless they were to move on very even ground, as sudden jerks, and turnings, would soon disorder them. But they may certainly be employed to ad-

vantage in all fixed engines, that are loaded with heavy weights ; especially when the power that operates is expensive, as men, horses, fire, &c. And in finer kind of engines, where it may be necessary to avoid any obstruction from friction as much as possible, the double, or treble wheels, where there is sufficient room, will reduce the quantity to any degree that can well be required.

Another advantage also arises from the application of these kind of wheels, that, if the motion is required to be extremely swift, though the pevets be as small as the weight they sustain can allow of, yet they scarce ever wear the holes they turn in ; for the last pevets in a treble set of wheels, which are the only ones that rub on a dead surface, will hardly make one revolution in two days.

There are several engines to which these wheels might be applied to advantage, even where the acting power costs nothing ; as watermills, where water is not always to be had plenty, which, by this means, would grind with much less water. Windmills, particularly, must receive great benefit from them ; the shaft being so large, the quantity of friction, which is in proportion to the part rubbing on a dead surface, must be greater in this, than most other engines ; besides, the rubbing part being wood, must still increase the quantity : I should therefore imagine, that, if the shaft were placed on wheels 5, or 6 feet diameter, it would not require above half the strength of wind, necessary at present. The frame in which these wheels might be placed, could easily be made in such a manner, as to be lowered, or raised ; so that if any inconvenience were found from too great velocity

velocity, when the wind increased, the shaft might then be let to turn in the usual manner. But there would be no danger of the shaft taking fire by any degree of velocity, whilst it turned on these wheels, as it would not then rub at all.

There have been many ingenious attempts, and some considerable improvements made, with respect to the saving of fuel necessary to work a fire engine, which is an article of great expence: but I do not find the diminution of friction has been considered as any ways material in this point, although it must necessarily reduce the quantity of fuel in proportion.

The power of a fire engine is estimated by the diameter of the cylinder and piston; on which the atmosphere presses, when there is a vacuum made by the condensation of the steam with which the cylinder has been filled. This power, or pressure, is deemed equal to 15 pound per inch square on a medium: but I should imagine, that the steam, with which the cylinder is filled, being water expanded into 4000 times it's bulk by the action of fire, when reduced to its original state by a strong injection of cold water dashing against the bottom of the piston, and mixing with it, must occupy such a space in the cylinder, as to hinder a perfect vacuum, which appears, in some measure, from the effects; for the power of the atmosphere on a fire-engine is seldom found to raise 7 pound per inch, and it can hardly require 8 pound per inch to overcome the friction of the several parts of the engine, and also to give a proper degree of velocity to the lever.

The friction of the piston moving up and down in the cylinder, and of the forcers or working rods, is
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in proportion to the diameter of the cylinders they work in. That of the plug frame, which is a piece of timber moved by the leaver through a wooden groove, by which the steam valve, and injection cock are opened and shut alternately, is pretty considerable; but the quantity proceeding from the several parts cannot be estimated with any tolerable degree of precision.

The whole weight to be raised, as also the superior power by which it is raised, center in the pivots of the axis of the great leaver, and the quantity of friction in the pivots, may be deemed equal to half so much weight hanging on them.

In order to form some estimate of the quantity of weight with which the axis of the leaver of a fire-engine is loaded, I took the dimensions of the several parts of that at the York-Buildings water-works; the leaver of which is 27 feet long, 2 feet 6 inches by 2 feet 2 inches in the middle, and 2 feet by 22 inches at the ends. The weight of which, with the archheads, chain, rods, and working frame hanging at one end, and the piston and chain at the other, may be computed at 6 tons, or 12,000 pound. The cylinder is 45 inches diameter, about 1591 square inches; which, at 15 pound per inch pressure of the atmosphere, is 22,274 pound. The pillar of water to be raised is 10,060 pound, which is not $6\frac{1}{2}$ pound per inch; so that the remainder of the power is employed in overcoming the resistance from friction in the several parts of the engine, and giving the leaver a degree of velocity equal to 120 feet per minute, which it moved in common work.

The weight of the power, or pressure, of the atmosphere taken at 14 pound per inch square, 22,274 pound, with the pillar of water 10,060 pound, and also of the lever, &c. 12,000 pound; amounting in the whole to about 22 tons, center in the axis of the lever. The quantity of friction resulting from this weight, supposed equal to half, or 11 tons, hanging on the pivots 6 inches diameter, the lever being 27 feet long, requires a power at either end = 425 pound to overcome its resistance in the least degree, and must still require a further power to overcome the friction of the other parts of the engine, and give the lever a degree of velocity = 120 feet per minute.

Before I give an account of the method I took to reduce the quantity of friction in the pivots, it may be proper to mention a general error in the manner of placing the axis of the lever under the beam. A balance, having its center of motion underneath, and equal weights at each end, being placed horizontally, will remain in that position; as both weights are equidistant from the center of gravity, which is perpendicular to the center of motion; but when it is made to incline to either side, it will continue to move on that side, untill it becomes parallel to the horizon, with the center of motion above the balance: for when either end is depressed in the least degree, as in fig. 3, it becomes more distant from the center of gravity; and the opposite end which is raised in proportion, is brought nearer to it, although both ends still continue equidistant from the center of motion.

Fig. 3. The lever A of this engine is 2 feet 9 inches from the upper part of the beam, to the center of it's axis B placed underneath; and weighs, with it's arch-heads, about 5 tons. When it was placed in a horizontal position, it required but $93\frac{1}{2}$ pound to overcome the resistance from friction in the pevets; but when either end was depressed 4 feet below the level, at which distance the springs are fixed, it required 534 pound to be applied to the opposite end to bring it back again: so that a power $= 440\frac{1}{2}$ was required, on account of the center of gravity being so much changed by the position of the axis underneath.

Fig. 4. To avoid this general error, I had the axis B placed on the upper side of the lever, and fixed by proper bolts and screws to a bar of iron equally strong, placed underneath: and, in order to reduce the quantity of friction, which is in proportion to the space rubbing on a dead surface in equal time, I had them made in the form *b* B, fig. 4, by which they are equally strong, though the rubbing part *b*, is but $1\frac{1}{2}$ diameter; so that by changing only the form of the pevets, the friction is reduced to $\frac{1}{4}$ of it's original quantity. I applied two quadrants, D D, to each of these pevets, whose radii are 2 feet 6 inches, by which the whole friction of the pevets *b* of the axis of the lever, are transferred to the pevets *d* of the quadrants, which are $1\frac{1}{2}$ inch diameter. These quadrants are equal in effect to wheels 5 feet diameter; the radius of which is $\frac{4}{5}$ to the semidiameter of its pevet, and reduce the friction in the pevets of the quadrants to $\frac{7}{10}$ th part of what it was in the pevets *b* of the axis; which \times by $\frac{4}{5}$ the reduction made by changing the form of the pevets $= \frac{1}{5}$ th: by which means the friction

friction that was in the pevets B, fig. 3. of the great axis, which was $\equiv 425$ pound, is reduced to $\frac{1}{180}$, or somewhat less than $2\frac{3}{4}$ pound.

Upon trial, the leaver, that before required a power of 95 pound to overcome the least resistance from friction, was as easily effected by the application of $\frac{3}{4}$ pound; and the resistance from friction occasioned by a weight of 6 tons is of so little consequence, that the leaver may be swung with a slight thread, and will continue in a state of vibration for several minutes after.

The original quantity of friction in the pevets B of the leaver A, fig. 3. which, when loaded with it's full weight 22 tons, required a power $\equiv 425$ pound to overcome it's resistance, is by this method reduced to 2 pound 10 ounces; and, if there were any need of reducing it further, it might be done by applying two small quadrants to each pevet of the larger, which would reduce it to one ounce or less.

It is not easy to determine the quantity of friction that was in the plug frame, but that has also been reduced to $\frac{1}{180}$ by the application of several rollers 5 inches diameter, whose pevets are $\frac{1}{4}$ inch diameter, on which it now moves. But it is evident that a power $\equiv 440\frac{1}{2}$ has been saved by changing the position of the axis of the leaver; and a power of 421 pound 6 ounces by reducing the quantity of friction in the pevets.

The visible effect, with respect to the working of the engine, according to the most exact observations by different persons, both before, and after these several alterations were made, is, that it now makes 18 strokes at 8 feet per stroke, for 15

that it ever made, with the same, or rather a smaller quantity of fuel; and must therefore discharge $\frac{1}{8}$ more water in equal time; which consequently saves $\frac{1}{8}$ of the fuel. But the effect is found still greater, as to supplying the tenants with water; for the engine performs the same service better now in 5 hours, than ever it did before in six: which can only be accounted for, by the extraordinary regularity of its stroke, which does not abate of its full length suddenly, as it used to do, when the strength of the fire abated: this I take to be occasioned in a great measure, from placing the axis above the lever, by which the center of gravity becomes reversed to what it was before; so that it requires the same power to keep the end of the lever depressed as low as the springs, that it required before to bring it back, when so much depressed; which is a particular benefit; for the stop, or sett, generally in large engines, when the ends of the lever come to the springs, is a defect that has been endeavoured to be remedied in some degree, by the help of the springs. But when the axis is placed above the lever, and the friction reduced, as in fig. 4, if one end is brought down to the springs, and let to return, it carries the other end down to the springs without any assistance, and will continue to do so several times, abating somewhat of the length of the stroke, each time.

This engine, from several improvements that have been made in the boiler, consumes but 4 bushels of coals in an hour; which is deemed $\frac{1}{3}$ less than others of equal bigness; and it performs the same work now in 20 hours, that it did before in 24 hours, it is a saving, in effect, of 16 bushels in 24 hours, amounting

mounting to 162 chaldrons in a year's constant work; which is a very considerable article, even where coals are to be had at a cheap price.

It may be proper to observe that the archheads C of the lever, must be drawn from the center of the small part *b* of the pevet, which turns on the quadrants. The quadrants and frame must be made sufficiently strong, which I had made of cast iron. The pevets of the quadrants are made of tempered steel, and turned true. There are four pillars G in the back plate of the frame, with shoulders, and strong screws, which pass through the fore plate, and are screwed tight by a nut *i*, when the quadrants are placed in the frame.

The back plate E (fig. 4.) of the frame, is longer than the fore plate F, in order to admit the iron bolts G at each end; by which the frame is screwed to a wooden block. The edges of the frame rest on a broad plate of iron, laid on a level board; upon which the blocks and frames are placed, and bolted down in the usual manner. The holes that the pevets of the quadrants turn in, are made in square pieces of brass *e*, riveted for the purpose into the frame plates.

The round part *b*, of the axis B, fig. 4, is made of hardened steel, and the edges *g* of the quadrants are also of the same metal; otherwise the very great weight they sustain, would make a deep impression in that part. There are two springs, *h h*, to each quadrant, which keep them in their proper places, and yield easily to the motion of the quadrants.

There was great care taken to make the frame square, and place the quadrants upright and level;
and

and also to place the leaver exactly in the center. By which means there has been no alteration required since they were first fixed ; and the engine continues to work as even, and true as it is possible.

I have applied wheels for reducing friction to some other engines with great advantage, which I shall take the liberty of laying before the Royal Society some other time ; and fear I have trespassed too much, on their patience already by this long detail.

XXIX. *The Difference of Longitude between the Royal Observatories of Greenwich and Paris, determined by the Observations of the Transits of Mercury over the Sun in the Years 1723, 1736, 1743, and 1753 : By James Short, M. A. F.R.S.*

Read June 2, 1763. **I**T will, no doubt, appear surprizing, that I should attempt to determine the difference of longitude between two of the most celebrated observatories in Europe ; and in which some of the greatest astronomers, that ever lived, have, for above eighty years, been constantly observing the motions of the heavenly bodies : yet it is most certain, that, to this day, we are ignorant of the said difference of longitude : the English astronomers reckoning it to be $= 9' 20''$, and the French setting it down at $9' 10''$, which, they tell us, was
found

